



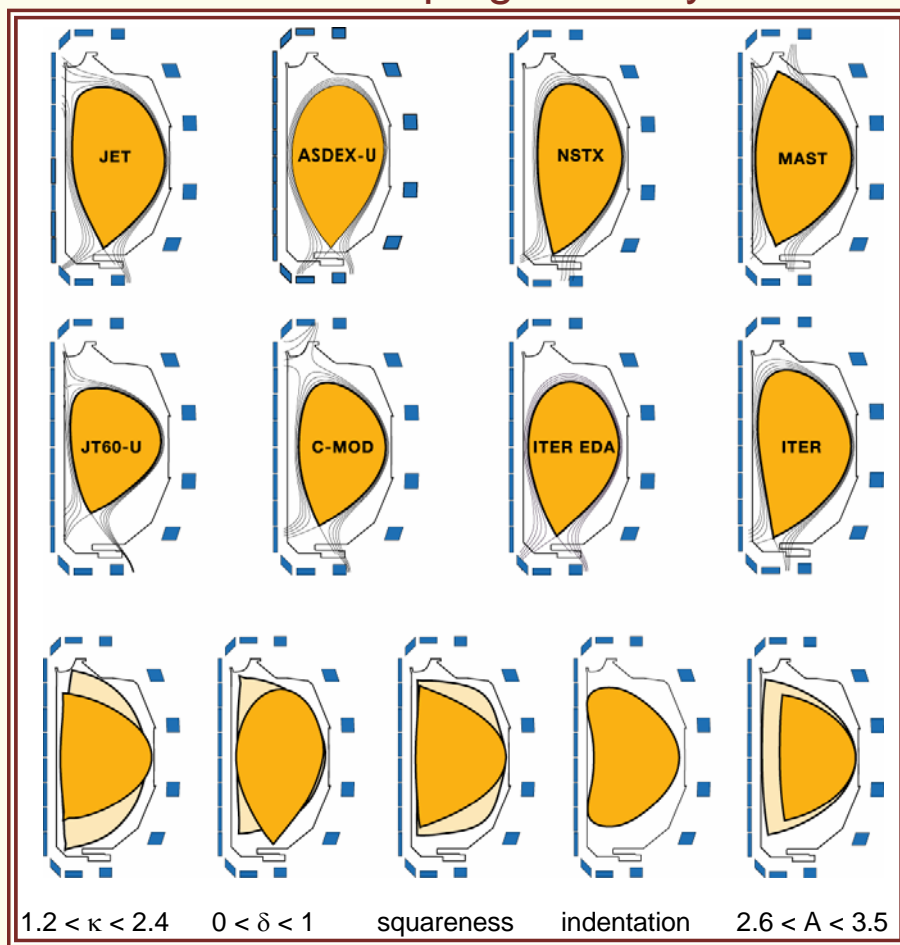
Macroscopic Plasma Physics

- Macroscopic plasma physics seeks to determine how to confine and sustain maximum plasma pressure efficiently in a magnetic field configuration.
 - Extremely important, since fusion energy production in a burning plasma facility (such as ITER) increases with the square of the plasma pressure
 - Useful dimensionless parameter β = plasma pressure / field pressure
- Key science topics addressed individually by first three topical questions (T1 – T3) defined in FESAC Program Priorities Report
 - Plasma Equilibrium and Magnetic Field Structure
 - Pressure-limiting Instabilities
 - External Control and Self-organization



Plasma shape can be altered to increase plasma pressure

DIII-D shaping flexibility

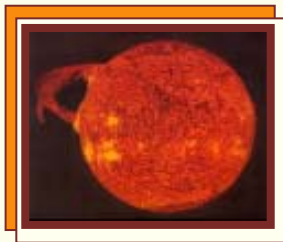


- All three facilities can match the ITER cross-sectional shape
- C-Mod: operates at, or above toroidal field of ITER (up to 8T)
 - Highest tokamak plasma pressure
- DIII-D: most flexible shaping
 - can produce a wide range of plasma shapes
 - can match the shapes of most machines
- NSTX: Low aspect ratio allows very high elongation, enabling very high β
 - world's only tokamak to study plasmas in the range of zero to unity (local) β



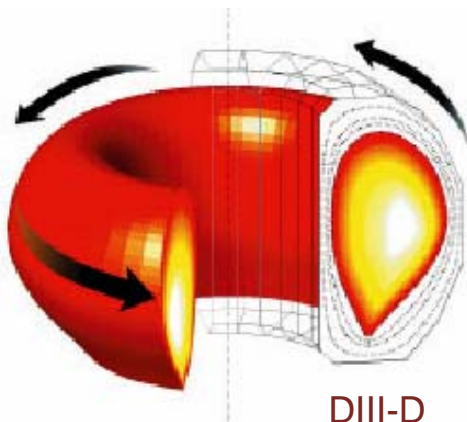
Instabilities can limit β in magnetically confined plasmas

- When plasma β exceeds an upper limit, large-scale unstable motions of the plasma can develop, leading to loss of confinement.
 - Kink/ballooning instability; edge localized mode (ELM)
 - Resistive wall mode (RWM)
 - Neoclassical tearing mode (NTM)
- Understanding the science of the stability limits set by these unstable modes is an essential goal of magnetic fusion research.
 - Plasma rotation can stabilize the kink/ballooning, and resistive wall modes.
 - Pressure, current, rotation profiles affect all modes including neoclassical tearing modes and ELMs
 - Modes and “error fields” can create drag that slows down the stabilizing plasma rotation.



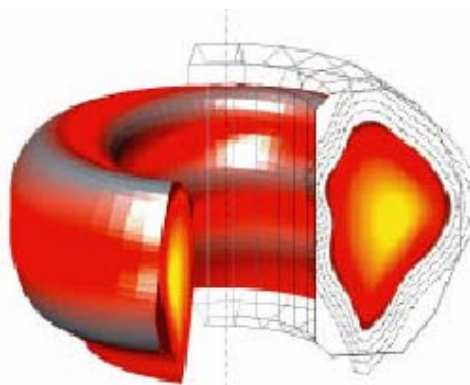
Instabilities can cause rapid loss of plasma pressure and current

Rotationally stabilized



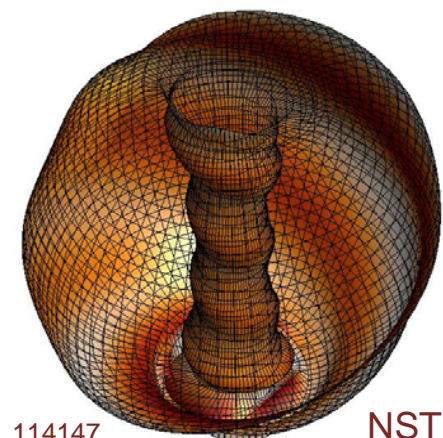
DIII-D

Unstable $n = 1$ RWM



DIII-D

Unstable $n = 1-3$ RWM



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NSTX

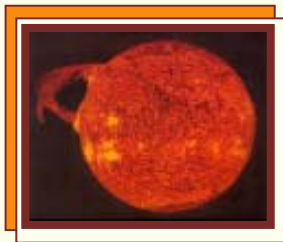
(surface distortions shown 10 times exaggerated)

- DIII-D, NSTX produce, and are diagnosed to study RWM, NTM, ELMs
- C-Mod, DIII-D can study
 - avoidance of rapid loss of pressure and current caused by instabilities (disruption)
 - mitigation of wall damage caused by disruptions

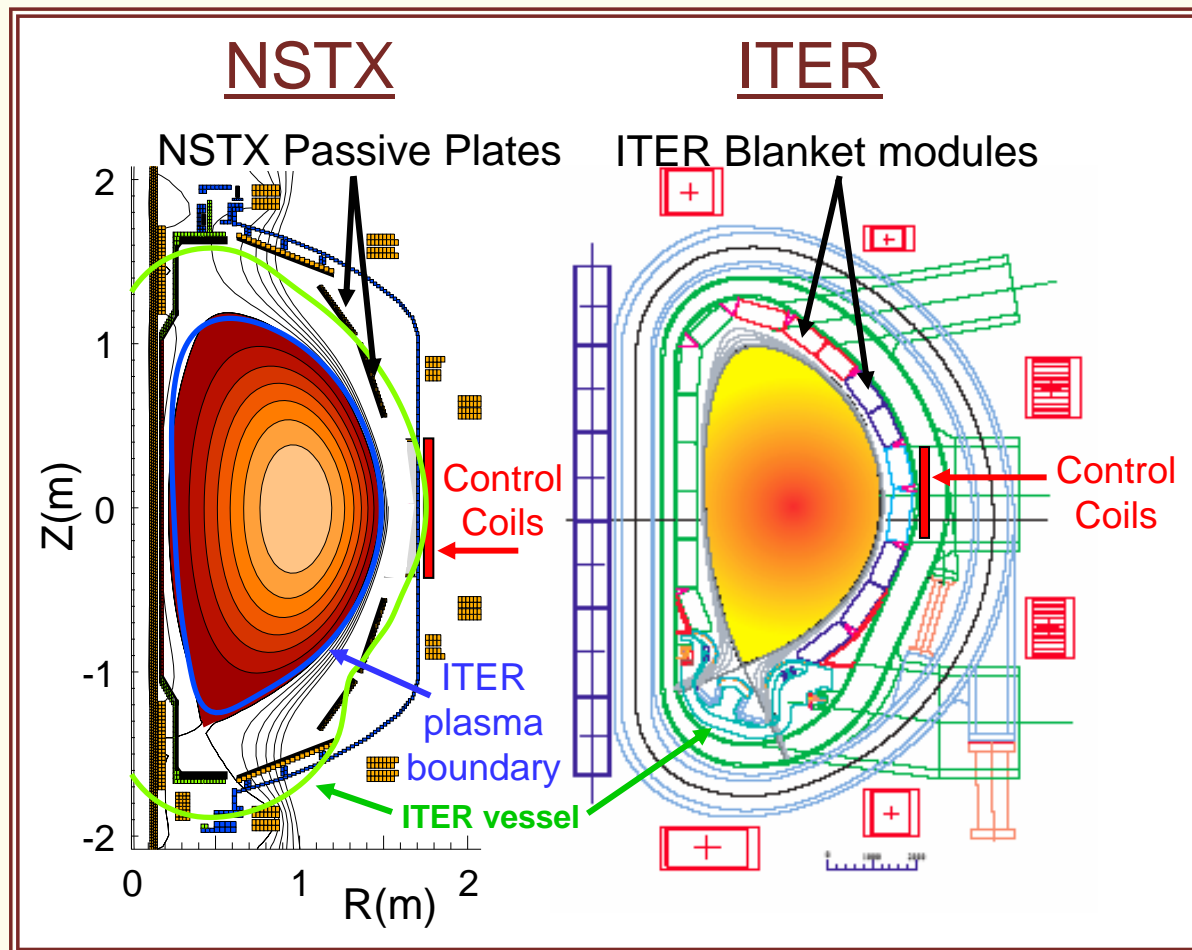


External Control and Self-organization

- Objective is to understand the fundamental science that will allow sustained, optimized fusion power production
 - All three national facilities are studying plasma self-organization and the proper balance between internal and external control.
- Plasma current is most efficiently sustained by “bootstrap” current that is self-generated by pressure gradients.
 - Large fractions of the total current—up to 85% in DIII-D, and 60% in NSTX
- Plasmas that are above instability limits can often be stabilized by external means, with a self-organizing plasma response.
 - DIII-D, NSTX can study external stabilization of the resistive wall mode.
 - DIII-D has demonstrated stabilization of neoclassical tearing modes using localized current drive from externally applied waves.
 - Within the next five years, C-Mod will address issues of bootstrap current generation and beta limits using lower hybrid current drive.



External control studies are providing validation for use in ITER



- Improvement of ITER design to include external control coils depends on studies of their effectiveness in DIII-D and NSTX.
- These coils are also being used for control and mitigation of edge localized modes.
 - ELM control and suppression critically important for ITER
- C-Mod plans to investigate lower hybrid current drive – an option for ITER.



The U.S. is a World Leader in Macroscopic Plasma Physics Research

- Scientific understanding of macroscopic plasma physics comes from a combination of experimental and theoretical investigation.
- Crucial experimental verification of theory requires facilities that can vary plasma conditions over an extended range.
 - The U.S. fusion program has a complementary set of three major experimental facilities that can access a very wide range of variations.
- The three major U.S. facilities contribute synergistically to this research.
 - *Combined* resources provide world leadership in scientific understanding
 - *Combined* resources provide physics validation for extrapolation to the burning plasma regime of ITER